

1.0 INTRODUCTION

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| 1.1 | TITLE OF THE ADVANCED TECHNOLOGY: | LEISA-Based Camera for High Performance, Low Mass, Low Cost, Spectral Imaging |
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| 1.3 | SPONSORING IPDT: | IT&A |
| 1.4 | CATEGORY OF PROPOSED USE: | Category III |
| 1.5 | SUPPLYING ORGANIZATION: | NASA/GSFC |
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2.0 BACKGROUND

2.1 **CHARACTERIZE THE ADVANCED TECHNOLOGY:**

We propose to construct a moderate-spatial, high-spectral resolution wedged filter hyperspectral (HS) imager to correct high-spatial, low-spectral resolution multispectral (MS) imagery from EO-1 and other next generation advanced imagers such as ETM+, Advanced Landsat (or LATI), and Resource 21, for the effects of atmospheric variability. This instrument will provide scientific return both in terms of improved imagery and hyperspectral sensing capabilities and will advance a number of technologies that are relevant to new wedged filter multi-head designs for a number of remote sensing applications. The proposed Linear Etalon Imaging Spectral Array/Atmospheric Corrector (LEISA/AC) uses a state-of-the-art wedged infrared filter (a linear variable etalon or LVE) placed in very close proximity to a two-dimensional IR detector array to produce a 2-D spatial image which varies in wavelength along one dimension. (The LVE is a wedged dielectric film etalon whose transmission wavelength varies along one dimension.) The filter has a 0.9 cm section which covers the 0.85 to 1.6 μm spectral region at a resolution of 30 - 40 cm^{-1} , (with a linear dependence of wavenumber on position) and a 0.1 cm section near the O_2 band at 0.76 μm with a resolution of about 200 cm^{-1} . This filter represents an advance in dielectric thin film technology. Reflective 1/4-wave stacked layers placed on both sides of one, or more, 1/2-wave etalon cavity(s) provide the spectral resolution. Order-sorting of the etalon is accomplished with lower resolution filter layers. In operation the two-dimensional spatial image is formed by an external optic, a small, wide field of view (FOV) lens in the case of EO-1, and the spectrum of

each point is obtained as the orbital motion of the spacecraft scans the image across the focal plane in wavelength thereby creating a three-dimensional spectral map. The spatial resolution is determined by the spatial resolution of the imaging optic, the image scan speed, and the readout rate of the array. For the EO-1 application, the single pixel spatial resolution is 360×360 radian² corresponding to a single pixel field of view of 250×250 m² (at nadir) at a 700 Km orbit, requiring a readout rate of approximately 30 Hz. The spectrometer has no moving parts, a minimum of optical elements and only one electronically activated element, the array. Compared to conventional grating, prism, or Fourier transform spectrometers and mechanically or electrically tunable filter systems, it represents a great reduction in optical and mechanical complexity. Furthermore, there are no difficulties associated with taking spectra over multiple wavelength orders, and the positional wavelength dependence and resolution may be tailored to a specific application and may vary over the array. LEISA/AC will use three identical 256×256 pixel IR detector focal plane assemblies in a single box. Each array will be placed behind a lens covering a five degree FOV to obtain a swath width of 185 km (15 degrees). The whole unit will be bolted to the spacecraft and bore-sighted with the large telescope used by the high-spatial resolution imager. The electronics necessary to interface with spacecraft C&DH will be contained in a separate box at a convenient distance from the focal plane assembly. Because the long-wavelength cut-off is 1.6 micron, the detector plane may be operated at ambient temperature (~300 K), however, to increase the signal-to-noise ratio, LEISA/AC will employ a thermoelectric cooler to stabilize the temperature at 285 K. Solar, lunar and ground targets will be used in-flight for calibration and flat fielding.

LEISA/AC is intended to correct for water vapor variations and to detect cirrus clouds (through the 1.38 micron channel) using the information in the 0.85 to 1.6 micron region and to provide an estimate of aerosol effects using both that spectral region and the 0.76 micron Oxygen band. The 0.45 micron MS data itself may be used to determine the effect of using shorter wavelengths in determining the aerosol effects. If this flight indicates that it is advantageous to include shorter wavelength and dark vegetation spectral regions for aerosol corrections then future atmospheric correctors will do so.

The LEISA concept was originally developed for the Pluto Fast-Flyby Mission (PFF) under the Advanced Technology Insertion Program. A pulse tube cooled, lower maximum spectral resolution, 1 to 2.5 micron, single head LEISA sounder is scheduled to fly as one of the major scientific instruments on the Lewis satellite built by TRW as part of the Small Satellite Technology Program (SSTP).

2.2 How will the utilization of this technology enhance science in the 21st Century?

The ability to accurately correct surface images for atmospheric state will allow full advantage to be taken of the better calibrated and higher signal-to-noise high-spatial resolution surface soundings to be performed by current and future instruments. LEISA/AC is a bolt-on instrument, which can be attached to any future earth imaging spacecraft.

2.3 Why is this considered a revolutionary technology development?

The combination of advanced wedged filters, high performance detectors, and multiple focal plane/optical systems in this instrument represents a unique approach for obtaining wide FOV hyperspectral coverage at relatively high spectral resolution with a significant reduction in complexity compared to conventional designs. The ability to co-align and register FOV's among multiple high resolution focal planes will advance the capability of future spectral imaging systems.

2.4 Why is a space flight necessary to validate this technology?

Spacecraft jitter will affect both the high spatial resolution multispectral and the moderate spatial resolution hyperspectral data in a way that would be difficult to simulate from a non-orbiting platform. It is also necessary to observe a wide swath (preferably greater than 100 km, but at a minimum 50 km) to obtain gradients in the atmosphere which may be used to relate the moderate spatial resolution data to the high spatial resolution data. These simultaneous wide swath measurements should be obtained with relatively low view angles, which is impossible from aircraft platforms. There are also, of course, questions relating to the stability of the filters, optics and detectors in a space environment which are best answered by an orbital test. Also, space flight allows a direct demonstration with Landsat-7 and MODIS.

3.0 PROPOSED INTEGRATION & VALIDATION APPROACH

3.1 Describe your proposed approach to incorporating this technology into the NMP/EO-1 flight and justify your categorization:

The LEISA/AC is a bolt-on instrument with an optics module containing the focal planes and an electronics module containing power supplies, interface electronics etc. The optics module would be attached to the spacecraft at a convenient location which allows a boresighted view of the multispectral ground scene. The electronics module can be mounted up to 2 meters away. Electrical and data interfaces with the spacecraft will be needed. Since this instrument enhances the ALI but is not required for its operation, it is a category III instrument.

3.2 Describe the approach presently in the budget which did not include the supplemental technology budget:

N/A: There is presently nothing in the original EO-1 mission budget for this instrument.

3.3 Describe how your proposed approach affects the original, baseline approach pursued by the Flight Team:

Requires mounting, power, telemetry thermal and data interfaces, and some optical co-alignment. On-orbit, solar and lunar calibration maneuvers will be required which will be coordinated with similar maneuvers required by the ALI.

3.4 Describe the interface with the spacecraft or the Advanced Land Imager (ALI):

The instrument will receive electrical power from the spacecraft. Command and telemetry will be via a 1773 interface and science data will flow via a RS422 interface.

3.5 Describe the impacts on the spacecraft or the ALI:

Spacecraft will be required to provide mounting, power, telemetry, and data handling, and will be required to sink the thermal load of both modules. On-orbit, solar and lunar calibration maneuvers will be required which will be coordinated with similar maneuvers required by the ALI. Spacecraft pointing and stability requirements will be less restrictive than those of ALI. Dark frame exposures will be required either of deep space or the unlit earth.

3.6 Describe your proposed approach to the integration and test of the advanced technology:

LEISA/AC will be tested, qualified and calibrated before integration with the spacecraft. It will be delivered in time to go through spacecraft environmental qualification. Full operation must be demonstrated with the spacecraft systems during qualification.

3.7 Describe your proposed approach to operations in general and to validation in particular for the advanced technology:

LEISA/AC operations will be planned in cooperation with ALI, Landsat-7 and MODIS observations. Data reduction and analysis will proceed with the primary objective of demonstrating the feasibility of correction for atmospheric variability. The validity of the correction will be determined by in several ways including: 1) Consistency of ground signal. Regions of the globe will be selected where there is expected to be little variation of the surface characteristics over short time scales, but where there is expected to be atmospheric variability. The MS images will then be variable because of fluctuations in the atmosphere, while images corrected using the LEISA/AC results should be show less variation. If available, ground measurements will be used to determine if the corrected MS images are consistent with the surface properties; and 2) Comparison of atmospheric parameters obtained from LEISA/AC with those measured by radiosondes, other satellite sounders, and so on. While this does not necessarily assess the accuracy of the atmospheric correction, it does provide a valuable consistency check. Intercomparisons with MODIS data will allow another method of calibration checks.

3.8 Describe the specific impacts on spacecraft resources:

Mass: 8 Kg (not including interface between FODB and RS422).

Power: 40 W (on); 0 W (off). A 10 minute warm-up period will occur before data is valid.

Thermal: Ambient (300 K). The focal plane will be cooled to 285 K with a TEC.

Volume: 2 boxes: optics module, 7.5" x 7.5" x 5.5" (with mounting feet, 7.5" x 8.5" x 5.5"; 8.5" x 5.5" mounting area) and an electronics module, 10" x 9.125" x 7" (with mounting feet, 11" x 9.125" x 7"; 11" x 9.125" mounting area)

C&DH: A data rate of ~ 95 Mbits/second will allow for single sampling in the in-track direction (16 bits/pixel). A data rate of ~190 Mbits/sec would allow for double sampling in the in-track direction and enhance the atmospheric correction capability.

Communication: Increased data transmission requirements set by volume of data acquired at rates given above.

ACS/pointing: The pointing requirements for LEISA/AC are nearly an order of magnitude less stringent than those required by the MS imager. Pointing maneuvers for solar and lunar calibration are required.

Flight S/W: Eight commands required for operation of the instrument, and thirteen elements of state-of-health information are read, including the three focal plane temperatures, the temperatures of the modules, 5 LVPC voltages and 3 array bias voltages.

Propellant: No specific impact.

Environmental: Dry N₂ purge during ground storage, dust-free controlled humidity environment.

Unobstructed FOV: 16 degrees x 6 degrees (nominal 15.1 degree x 5.3 degree FOV).

Glint Avoidance: TBD

Sun Avoidance: Short (a few minutes) exposures to the sun are tolerated. Longer exposures should be avoided.

3.9 Describe how we would contractually acquire the advanced technology and identify the deliverables:

The instrument would be supplied by NASA's Goddard Space Flight Center mostly using funding sources outside of the NMP/EO-1 Flight (see budget page for funding breakdown). The instrument is the deliverable.

3.10 Describe any facilities issues or special GSE or FSE:

Testing of the hardware will require simulators for the spacecraft C&DH systems, or at least those subsystems which would command the instrument and accept data from the instrument. These can be software simulators.

4.0 AVAILABILITY

4.1 **Identify the earliest date when an ETU or comparable demonstration hardware (and/or software) would be deliverable to the Flight Team:**

An electrically and mechanically functional engineering unit will be available in December 1997. A form and fit engineering model (no electronics) could be available within three months after interface requirements are fixed.

4.2 **Identify the earliest date when flight hardware (and/or software) would be deliverable to the Flight Team:**

The flight hardware would be deliverable by July, 1998 (nine months before launch). The unit would be available for a one-week flatsat test in June 1998.

5.0 RISK

5.1 **Characterize the technical risk associated with this advanced technology. Identify specific risk mitigation approaches to the technical risk that you would recommend.**

There is some risk associated with attempting to push the resolution of the wedged filters to 30 - 40 cm^{-1} throughout the 0.85 to 1.6 micron region, since 30 cm^{-1} corresponds to a resolving power (/) of 400 at 0.85 μm , which, while probably feasible, is beyond the current state-of-practice. Somewhat lower resolution filters exist through most of this spectral region, however, and, while they are not optimal for the task, they would provide sufficient resolution to accomplish most of the goals. The very low dark current "room temperature" detectors also do not presently exist, but there is a high probability of their successful fabrication within the required development schedule. Higher dark current detectors or shorter wavelength cutoff detectors are available now which could be used to accomplish many of the goals of the program.

5.2 **Similarly, characterize the schedule risk associated with this advanced technology. Identify specific risk mitigation approaches to the schedule risk that you would recommend. Identify any schedule "trigger points" that represent decisions to shift to alternative development paths.**

Since this is a category III development, there would appear to be no schedule risks to the EO-1 mission associated with it. The long-lead items are the very high resolution wedged filters and the very low dark current detector arrays since these are both developmental items to some extent. However, there are currently available alternates in both cases which would allow for successful attainment of most of the goals, which could be obtained on shorter notice if it became necessary. Our experience is that we can modify our schedule in the later stages to allow late delivery of the filters, while continuing to assemble and test the instrument.

- 5.3 Characterize the budgetary risk associated with this advanced technology. Identify specific risk mitigation approaches to the budgetary risk that you would recommend. Identify the total budgetary reserve you would recommend to make the aggregate risk of incorporating this candidate technology acceptable.**

Our budget estimate is based on experience building LEISA for the Lewis mission. The LEISA/AC instrument excluding spacecraft interface costs is primarily being funded outside the EO-1 budget (see budget page for funding breakdown). If costing difficulties are encountered, then fewer spare parts will be purchased, commercial parts will be used more extensively in the instrument, and thermo electric coolers will not be used to stabilize the focal plane temperature. A total budgetary reserve of \$67 K is suggested.

6.0 BUDGET

- 6.1 Determine the net cost to incorporate and validate the candidate technology by using a spreadsheet comparison between the budget distribution for the current approach pursued by the Flight Team and that of the advanced technology. Identify any cost-sharing with the supplier. Identify funding for fiscal years 1997 through 2000 and subdivide the entries into Development, Integration & Test , and Operations which includes the validation of the candidate technology. Be sure to include and highlight the cost of the risk mitigation approaches you recommended under Risk.**

The following table outlines the budget profile and work schedule for the LEISA / Atmospheric Corrector. Previous investment in the LEISA instrument concept has included \$360 K from the Pluto Fast Flyby Advanced Technology Insertion RTOP and \$540 K funding under the Small Satellite Technology Initiative. The SSTI instrument has a somewhat different configuration, has already been completed and is to fly on the Lewis spacecraft built by TRW. In addition, for the Lewis application, TRW supplied about \$1200 K of equipment support including, but not limited to, a pulse tube cooler and its associated controls, a steerable mirror and its associated controls, and the instrument mounting assembly.

ATMOSPHERIC CORRECTOR Budget Profile/Work Schedule

<u>Year</u>	<u>Quarter</u>	<u>\$K</u>	<u>Comments/Schedule</u>
FY'97	1	150	Filter PR, optical, mechanical, electrical design
	2	300	Array PR, continue design, begin parts purchase
	3	200	Begin fabrication, begin testing, finalize design
	4	200	Engineering model, Engineering tests
Subtotal (FY'97)		850	
FY'98	1	400	Mechanical, optical and electronic fab
	2	175	Assembly
	3	75	Test and Calibrate

	4		Delivery
Subtotal (FY'98)		650	
FY'99	1	168	Spacecraft integration
	2	85	System testing
	3	20	Launch
	4	10	Initial on-orbit validation (operation only)
Subtotal (FY'99)		283	
TOTAL (FY'97 - FY '99)*		1783	
-Supplied by RTOP (MTI)		1000	
-Spacecraft Accommodation		168	
SUPPLIED BY PROJECT		615	

* Instrument: \$1605 K, I&T and Validation: \$178 K. **Only requires \$615 K Project Support.** These estimates do not include reserve, for which a value of \$67 K is suggested (see section 5.3)

7.0 MANPOWER

The entire instrument development from FY '96 through the third quarter of FY' 99 including design, fabrication, testing, calibration and initial on-orbit validation (verification of correct operation only, not long term product verification) will require 9.1 personyears. Approximately 7.1 personyears will be required for optical, mechanical, thermal and electrical design and 2 personyears will be required for testing, I&T and pre-launch calibration. The project is only being asked to support 0.8 personyears, while the rest of the requirements are being met by shared support with other projects.

8.0 RECOMMENDED DISPOSITION

Justify the incorporation of this advanced technology on the NMP/EO-1 Flight. Weigh the benefits described in the Introduction against the accommodation impacts associated with budget, schedule, and overall risk. Is the NMP/EO-1 flight a suitable, cost-effective testbed for this technology? How well does this candidate technology contribute to the most robust technology mission that we can afford?

The LEISA/AC should be incorporated into the EO-1 Flight in order to allow for the correction of the high-spatial resolution multispectral (and hyperspectral) data for atmospheric effects, thus increasing the usefulness of the data and validating the approach for future land sensing missions. In addition, the EO-1 Flight path will allow close time coincidences with Landsat-7, so the EO-1 atmospheric corrector could correct operational Landsat data (at least in a test mode). Close flights with the EOS AM1 satellite to allow for intercomparisons with the MODIS sensor. Furthermore, there is new science to be obtained from hyperspectral data in the 0.85 to 1.6 micron region. Since this is a low power, low mass, small volume, bolt-on, non-cryogenic instrument, the most serious impact to the EO-1 mission will be in the increased data rate and

storage required. The impact on the schedule and the overall risk to the mission of non-completion is negligible since it is a category III instrument. There are a number of technologies and methodologies being flight validated by this instrument including high spectral resolution, small wedged filters; low dark current, high temperature IR arrays; multi-optical wide FOV synthesis; and solar and lunar calibration/flat fielding.